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RESEARCH PAPER

Assessment of forest geospatial patterns over the three giant forest areas of China

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Abstract: Geospatial patterns of forest fragmentation over the three traditional giant forested areas of China (Northeastern, southwestern and Southern China) were analyzed comparatively and reported based on a 250-m resolution land cover dataset. Specifically, the spatial patterns of forest fragmentation were characterized by combining geospatial metrics and forest fragmentation models. The driving forces resulting in the differences of the forest spatial patterns were also investigated. Results suggested that forests in southwest China had the highest severity of forest fragmentation, followed by south region and northeast region. The driving forces of forest fragmentation in China were primarily the giant population and improper exploitation of forests. In conclusion, the generated information in the study provided valuable insights and implications as to the fragmentation patterns and the conservation of biodiversity or genes, and the use of the chosen geospatial metrics and forest fragmentation models was quite useful for depicting forest fragmentation patterns.

Key words: forest fragmentation; landscape pattern; land cover map; moving window analysis; fragmentation models; China

Introduction

Forest fragmentation refers to the process of subdividing the previously large and continuous extensions of forests into relatively small and isolated patches (Haila 1999). Generally, it results in a loss of original habitat for some plant and animal species, reduction in patch size, increasing isolation of patches and an increase in edge at the expense of interior habitat, and negatively impacted the fitness of forest-dependent organisms to the environment. Increased forest fragmentation due to natural and anthropogenic disturbances, such as wildfire, soil erosion and landslide, deforestation, urban sprawl etc. poses an increasingly serious threat to biodiversity conservation, water quality, also endangers the sustainability of ecological goods and services from forestland (Lovejoy et al. 1986; Vogelmann 1995; Laurance et al. 1997; Riitters et al. 2000). Currently, the economic, environmental and cultural losses caused by forest fragmentation have attracted great attention world-widely. In China, the current characteristics of forests can be summarized as uneven spatial distribution, low productivity, unsuitable age-class composition for sustained yield, let alone sustainable forest management, and improper or even unlawful exploitation of forest resulting in the sharp decline in the quantity and quality of natural forests (Li 2004; Peter 2006). Li (2004) stated that at least 200 plant species have become extinct in China since 1950s, and more than 61% wildlife species were subjected to severe habitat losses. Changes in forest composition have also caused severe ecological and environmental disasters. For example, insect infestations damaged over 9.3 million ha of forests annually, caused the timber loss of more than 10 million m^3. Flooding, in partly the result of loss of natural vegetation cover caused a total loss of 20 billion US dollars in the summer of 1998 alone. In past years, Chinese government invested and started several key forest systems and programs to preserve forest resources and to improve the ecological situation. The effects of these projects have been evidenced by a large-scale increase of man-made plantations in non-forested regions. For instance, the total forest coverage area has being increased annually in southern China and central China. Meanwhile, the roles of employees in forestry sectors are shifted from forest logging to afforestation and multiple uses. The aforementioned spatio-temproal changes in Chinese forestry have largely altered the patterns of forest fragmentation. However, up to date, forest fragmentation at the national

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and regional scales remains an issue because studies on the nationwide forest fragmentation are rarely available. Consequently, the extent and rate of forest fragmentation in China are not understood clearly by the public, particularly, by the policy-makers and governmental agencies at various levels.

The primary objective of this research was to explore the spatial differences of forest fragmentation over the giant forested areas, including northeast region, southwest region and south region of China based on the quantification of diverse geospatial metrics and the execution of forest fragmentation models. These three regions were chosen as our research focus due to the overwhelming predominance in forest area, regional forest coverage and their distinct forest management practices (Li 2004; Peter 2006; Zhang et al. 2006). The information generated from this study suggests that spatial configuration pattern of forest fragments at landscape level should be taken into consideration in forest conservation strategies and practices of land use planning in China.

Materials and methods

Data

Land cover dataset for China, with a 250-m spatial resolution, was used to characterize the spatial patterns of forest fragmentation over the three forested areas (Fig. 1). This dataset for 1995 was provided by the Institute of Geographic Sciences and Natural Resources, CAS (Chinese Academy of Sciences) based on Landsat TM imagery. In this land cover, 30 land cover classes were derived from the spectral information of TM data and other ancillary GIS-based thematic information.

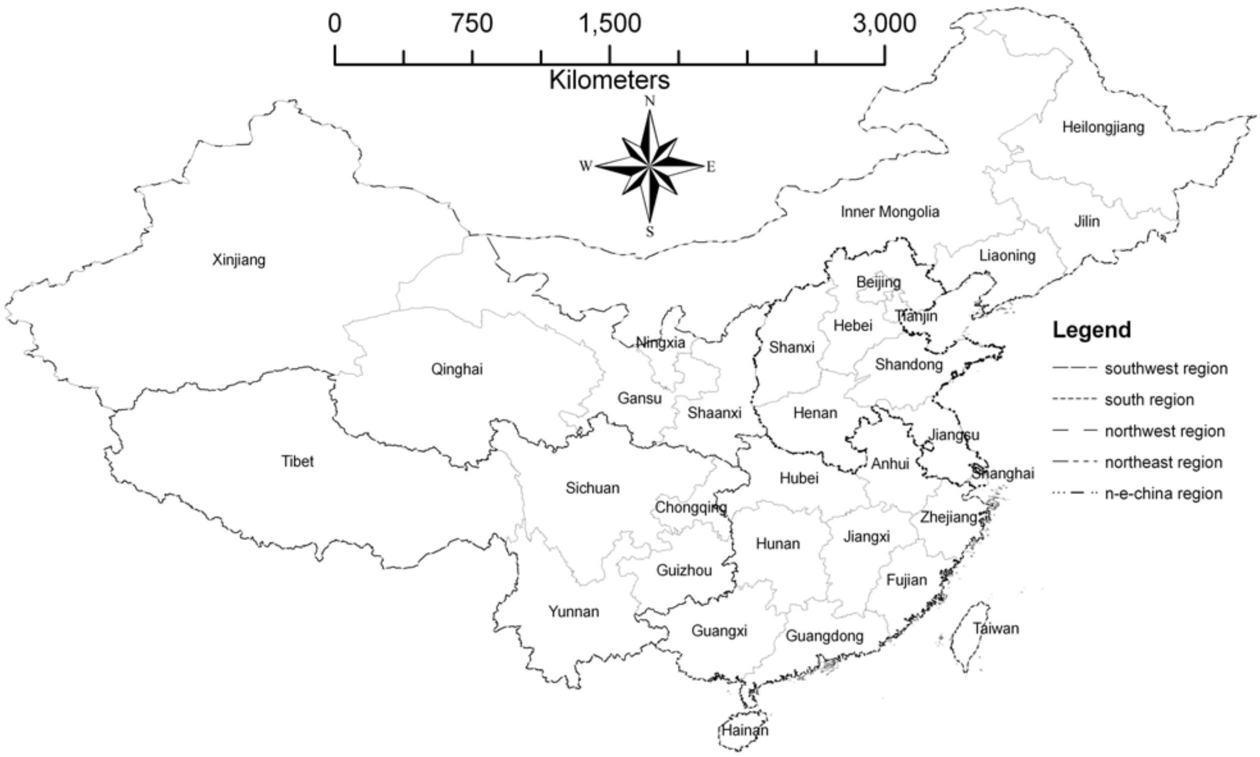

Fig. 1 Administrative delineation map of China for the forest fragmentation analysis

Note: Northeast region consists of Inner Mongolia, Heilongjiang, Jilin and Liaoning provinces; Northwest region covers five provinces, including Xinjiang, Qinghai, Gansu, Ningxia and Shaanxi; N-E-China is composed of three municipalities of Beijing, Tianjin, Shanghai, five provinces of Hebei, Henan, Shanxi, Shandong, Jiangsu; Southwest region is composed of Tibet, Sichuan, Guizhou and Yunnan South region is constituted of eight provinces of Anhui, Hubei, Hunan, Jiangxi, Zhejiang, Fujian, Guangxi, Guangdong; Hainan and Taiwan

Prior to analyzing forest spatial patterns, the identified land cover classes were aggregated to concentrate on the pattern of forest versus non-forest land cover (Table 1). Three land cover classes, namely forest (natural and man-made), open forest or woodland and other wooded land, were grouped into one forest class. Six land cover classes, including river, lake, reservoir and ponds, permanent ice and snow, bare soil, and bare rock, were grouped into the missing class, which is not permitted to fragment the forest in our analysis. Then the remaining 21 land cover classes were combined into the non-forest class. Because the non-forest land cover types were aggregated, our analysis will not attempt to distinguish the specific type of non-forest land

cover associated with forest fragmentation.

Table 1. The aggregation of 30 land cover classes into forest, non-forest and missing classes for the fragmentation analysis

Aggregated class	Original land cover class	
Forest	Forest (natural or man-made), Open forest or woodland	Other wooded land
Non-forest	Shrub, Dense grassland, Moderate grassland	Irrigated crop-plain
	Sparse grassland, Beach and shore, Bottomland	Dryland crop-mountain
	City built-up, Rural settlements, Other commercial site	Dryland crop-hill
	Sand, Gobi, Salina, Wetland, Alpine desert and tundra	Dryland crop-plain
	Irrigated crop-mountain, Irrigated crop-hill	Dryland crop-slope>25d
Missing	River, Lake, Reservoir and Ponds, Permanent ice and snow	Bare soil, Bare rock

The missing class was ignored, only the non-forest classes were permitted to fragment the forest class.

Methods

Provinces, municipalities and autonomous prefectures of China were grouped into 5 regions to highlight the regional differences in strategies and practices of forest management (Adopted from Zhang et al. 2006), ignoring those regions with low priorities in ecological merits. The detailed delineation was illustrated as shown in Fig. 1. According to the delineation, our research on the assessment of forest spatial patterns was mainly focused on the three traditional giant forested areas, namely northwestern, Southwestern and Southern China for their overwhelming predominance in the percentage of forest area and forest coverage.

The extraction of landscape ecological indices and the analysis of moving window technique were involved in this research to characterize the difference in spatial patterns of forests over the three regions. The former was performed using the IAN image analysis program developed at the University of Wisconsin and being available at http://landscape.forest.wisc.edu/projects/ian/. For the latter, we developed applications based on ENVI/IDL and ERDAS Modeler to fulfill forest fragmentation models outlined by Riitters et al. (2000 and 2002). Two fundamental measurements for identifying patterns or categories of forest fragmentation were derived prior to running the models. Given the window size, the first measurement is Pf, simply the proportion of non-missing pixels within the analytical window that are forest the second is Pff, the ratio of the number of forest pixel pairs in cardinal directions over the total number of pixel pairs (either both or one of pixel pairs is forest) in cardinal directions. Generally, Pff measures the conditional probability that a pixel adjacent to a forest pixel is also forest pixel. A large Pff value indicates a high connectivity of forest pixels. Once Pf and Pff are both available, each forest pixel in the landscape would be labeled as one of the six fragmentation patterns or categories (interior forest, perforated forest, edge forest, patch forest, transitional forest and undetermined forest) in accordance with the discriminant criteria defined by the models.

To effectively implement the analysis of moving window, the first step is to determine the size of the sliding window. Riitters et al. (1997 and 2000) argued that the moving window size was ultimately related to the resolution of the data and the size of the smallest object of interest. In this case, we worked with a 250-m resolution land cover dataset and the smallest object of interest with only a single pixel. In our study, the moving window size ranging from 3 × 3 pixels to 13 × 13 pixels was applied to explore the effects of different window sizes on the six fragmentation components. As a result, we found that the increased window size led to an abrupt decrease in the interior forests and a rapid increase in the edge forests, while the remaining types of fragmentation remained relatively stable (Fig. 2). The 3 × 3 pixels moving window size was ultimately identified to analyze the fragmentation patterns based on the above findings. Because the window size maintained a fair representation of the proportion (Pf) of pixels in the window and made the interior forest reach an appropriate level. Thus, an image with a single pixel wide (250 m) border could be generated to properly reflect the actual situation of forest configuration in China.

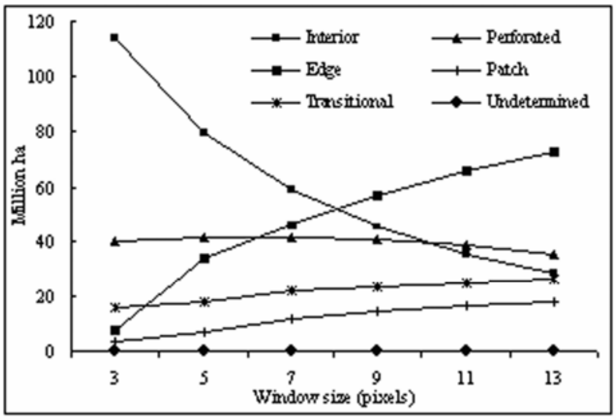

Fig. 2 The impacts of moving window sizes on diverse fragmentation components

Results and discussion

Forest area

Forest statistics were derived based on land cover dataset for 1995, in conjunction with the regional delineation map (Fig. 1), and listed in Table 2. At the national scale, total forest area was around 179 million ha and overall forest coverage was approximately 18.92%. In contrast, forest area of mainland China in 1998, issued by the official, was about 157 million ha (SFA, 2001), apparently existing a gap of 22 million ha with the former.

The possible reasons may be summarized as follows: (1) the officially statistic forest area was just for mainland China (SFA, 2001) as compared with the area derived from land cover including Taiwan area; (2) there was a 3-year time lag between the two statistics, during the period, natural and anthropogenic disturbances might contribute to the decline; (3) the definition of “forest” used in this study was not totally consistent with that used in SFA report in 2001; and (4) the measurement scales between land cover and official estimation was also different. In our research, forest area statistic was derived from the classifications of remotely sensed imagery while the official statistic was obtained from systematic sampling estimation. In this land cover (resolution 250 m), a single pixel occupied an actual area of 6.25 ha. Obviously, mixed pixels did exist in the land cover, raising the area errors for various types of land cover.

Table 2. Forest statistics for 5 delineated regions of China derived from the land cover for 1995

Region	Forest area (ha)	Percentage of forest area (%)	Forest coverage (%)
Northeast	46379856	25.79	23.98
Northwest	8699375	4.84	2.87
N-E-China	7972437	4.43	9.99
Southwest	43372575	24.12	18.53
South	73413987	40.82	51.99
China	179838231	100.00	18.92

Table 2 exhibits the forest statistics for the five administrative regions delineated. Maximum percentage of forest area and forest coverage verified in south region was 40.82% and 51.99%, respectively, followed by that in northeast region and southwest region. The accumulative percentage of forest area for northwest region and N-E-China was less than 10%. Thus, northwest region and N-E-China were excluded out the analysis of forest spatial patterns to highlight the priorities of the three traditional forested areas of China. Zhang et al. (2006) presented the statistics of forest area and forest coverage in 1998 over 6 six defined administrative regions and mainland China, respectively, using panel data from 1990 to 2001. In contrast, there was only a slight difference in the national forest coverage between Zhang’s statistics (16.34%) and our result (18.92%). Inconsistencies of geospatial extents and data sources were viewed as the major driving factors, and may be responsible for the statistical difference.

Forest fragmentation Patterns derived from landscape metrics

Aggregation Index (AI), Core Area Index (CAI), Edge Density (ED), Fractal Dimension (FD), Total Polygons (TP) and Coefficients of Variation for Shape Index (CVSI) were picked to quantify the forest fragmentation patterns due to their popularities in assessing landscape patterns at the local, regional and global scales, after reviewing recent studies on forest fragmentation (Fuller 2001; Staus et al. 2002; Butler et al. 2004; Garcia-Gigorro and Saura 2005; Abdullah and Nakagoshi 2007; Saura and Castro 2007). Measurements of the above indices for metrics described earlier were derived by running IAN software and summarized in Table 3.

Table 3. Forest geospatial metrics for three traditional forested areas of China derived from the land cover for 1995

Metrics	Northeast region	Southwest region	South region
Aggregation Index	0.91	0.88	0.90
Core Area Index (%)	68.39	59.34	64.39
Edge Density (m/ha)	14.49	19.74	16.19
Fractal Dimension	1.42	1.43	1.43
Total Polygons	18593	24704	22229
Coefficient of variation for shape index	0.82	1.09	1.05

One of the basic symptoms of forest fragmentation is an increase in number of patches and a reduction of mean forest patch size (Echeverría et al. 2006). In our case, the total number of forest fragments increased from 18 593 in northeast region to 22 229 in south region, then to 24 704 in southwest region (Table 3). In southwest region, 7.19% forest patches was concentrated in a large patch of approximately 1 256 ha, and about 79.59% forest patches occurred in isolated patches of less than 313 ha (Fig. 3). In south region, 4.13% forest patches fell under the large patch group and 84.79% forest patches belonged to the small size group. Examining the northeast region, 3.84% forest patches was found in the large patch group and 86.24% forest patches belonged to the small patch group. These statistics indicated that forests in southwest region were more fragmented than those in south region and northeast region. By analyzing the temporal changes in forest patch number and its statistical distribution over patch size, Luis et al. (2006) and Cristian et al. (2006) presented the similar conclusions on forest fragmentation patterns over time interval of 1975 through 2000. The former was focused on the tropical montane forests in Mexico, whereas the latter aimed at the rapid deforestation and fragmentation of temperate forests in Chile. Unlikely our analysis on fragmentation just focused on the spatial differences over the three forested areas of China at the same time stage.

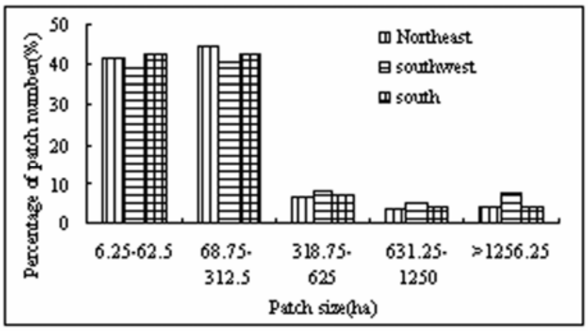

Fig. 3 Spatial variation of forest fragment size over the three forested regions of China.

Values of the bars represent the percentage of fragments belonging to each size interval

Edge density (ED) standardizes edge to a per unit area, facilitating comparisons among various landscapes in size. It was

regarded as a good indicator of forest fragmentation, which the more fragmented patterns, the higher ED values are (Li et al. 1993). ED measurements revealed that forests in southwest region was at the highest fragmented status, with a scale of 19.74 m/ha, followed by south region (16.19 m/ha) and northeast region (14.49 m/ha).

In the research of landscape ecology, patch shapes are frequently characterized via the fractal dimension (Turner 1990; Riitters et al. 1995). The scale of fractal dimension is a multiscale description of patch shape complexity, and scales between 1.00 and 2.00 for two-dimensional objects. Higher fractal dimensions indicate more complex polygons or patches. In this study, FD measurements over the three forested areas were quite close to each other (Table 3), 1.43 (1.433) for southwest region (After checking the original value derived from IAN software, with three places of decimals for measurements, the actual value was 1.433), 1.43 (1.431) for south region and 1.42 (1.424) for northeast region. Thus, a weak decreasing trend in forest fragmentation over space was confirmed from southwest region to south region, then to northeast region. The AI measurements also exhibited the same situation, which further consolidated the fact of fragmentation occurred in the three forested areas.

The fact mentioned above was further verified by examining the remaining metrics (CAI and CVSI).

Forest fragmentation Patterns derived from the fragmentation models

By means of spatial filtering analysis at the 3 × 3 pixels window size, each forest pixel in the land cover was classified into one of the six fragmentation components. The spatial patterns of forest fragmentation and regionalized statistics derived were demonstrated as Figs. 4 and 5.

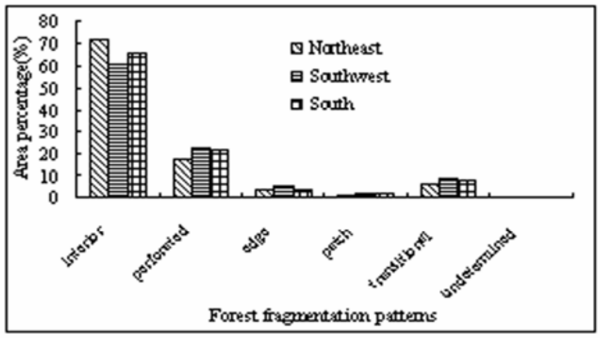

Fig. 4 Area percentages of six forest fragmentation patterns derived from land cover over the three major forested regions of China

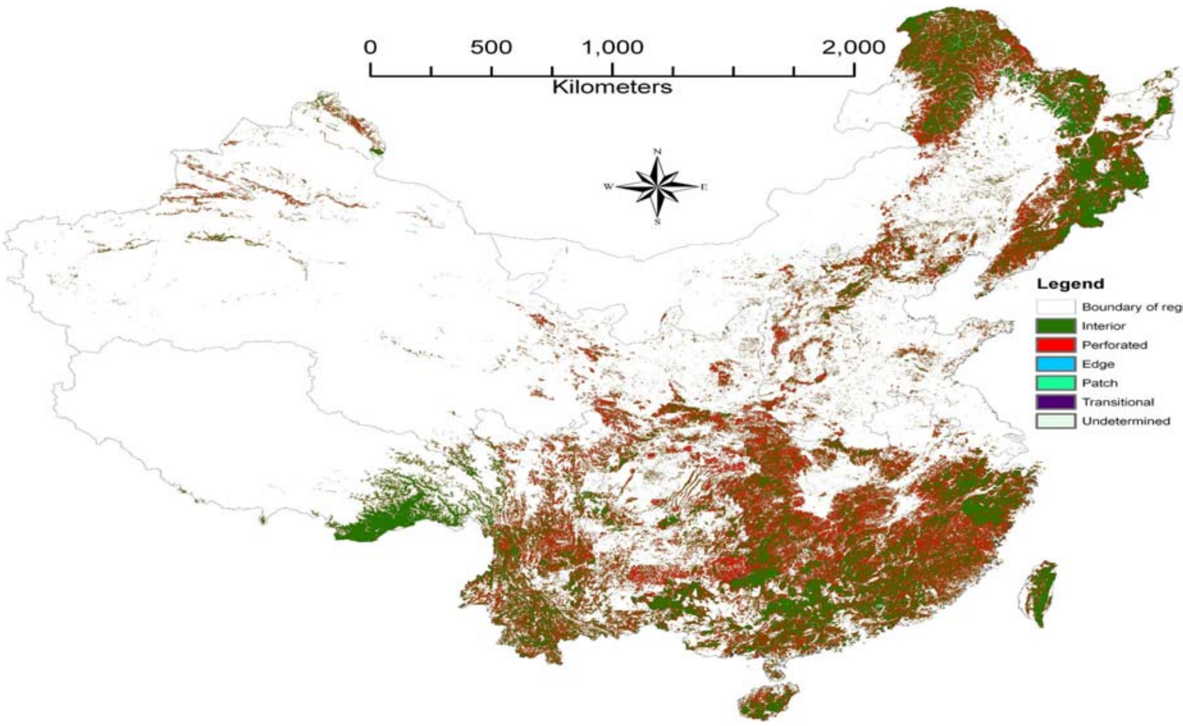

Fig. 5 National map derived from implementing forest fragmentation models at 3 × 3 pixels **sliding window size to depict the spatial characteristics of six forest fragmentation patterns in China**

As shown in Fig. 4, 71% and 18% of forests were labeled as interior forest and perforated forest, respectively, in northeast region, 60% and 23% in southwest region, and 66% and 22% in south region. The percentage of interior forest classified suggested that southwest region had the highest severity of forest fragmentation, followed by south region and northeast region. This finding derived from the models was coincided with that derived from all landscape metrics (Table 3). Ritters et al. (2000

and 2002) examined the forest fragmentation patterns at the global scale using a 1-km land cover maps and the national forest fragmentation patterns of conterminous Unites States using a 30-m land cover product, NLCD-1992 (National Land Cover Dataset). The successful use of the fragmentation models characterizing the forest fragmentation patterns at different scales (global and national) and different resolution (1 km and 30 m) was well documented. In our research, we just followed the models to depict the forest fragmentation of China at one time stage using the 250-m land cover product. Thus the reliability of our study results derived from the same models was confirmed.

Identification of driving forces for forest fragmentation

In the study, the exhibited forest fragmentation and degradation was mainly caused by unsound exploitation, forest fires and forest pets and diseases (Li 2004). Rapid population growth, coupled with the development of agriculture, industry and construction, the over-exploitation of forest resources and subsequent cultivation on steep slopes led to the deterioration and fragmentation of forest ecosystems. Southwest China, consisting of Tibet, Sichuan, Chongqing, Yunnan and Guizhou, is characterized by the traditional agriculture and steep topography. The natural segmentation of plentiful ridges, valleys and rivers, in conjunction with the anthropogenic cultivation at the expense of forest resulted in southwest region the top severity of forest fragmentation among the three forested areas, with the lowest percentage of interior forest and the highest percentage of perforated forest, edge forest, patch forest and transitional forest (Fig. 4).

The south region is typically a collective forest area, and the share of state-owned forest is less than 10% (Zhang et al. 2006). Plantations predominate over natural forest in this region. Due to the suitable temperate weather, plantation forest grows very fast and has a short rotation of less than 10 years. Accordingly, frequent reforestation and deforestation practices in this region altered the land cover types with a high frequency. Therefore, the unique forest management strategies for plantations were viewed as the major factor resulting in the forest fragmentation in this region. Examining the northeast region, it is characterized by traditional forestry and gentle terrain covered by natural forest. It is a large supplier of timber to other regions. However, the production of timber in this region has become second to the southern China due to the degradation of forest resources resulted from uncontrollable and improper exploitation of forest happened in 1950s through 1990s. Logging and wildfires were the principal controls for forest fragmentation occurred in this region.

Implications from national forest fragmentation map

National forest fragmentation map spatially illustrates the characteristics of forest fragmentation in China (Fig. 5), also conveys their spatial differences among the three major forested areas. The interior forest information is quite beneficial for the planning and establishment of nature reserves at national and regional scales, especially for the habitat analyses of certain valuable animal and plant species to sustain their own populations and the conservation of biodiversity or genes, in accordance with their minimum area requirements. Ecologically, insufficient quantity of habitat supporting individuals and viable populations is directly associated with the interior forest information. Pitifully, the interior forest information could not indicate the information of habitat quality. The information on perforated forest presented implies the occurrence of logging patches and fire scars etc., which helps guide our forest management practices to reduce the risks of forest fragmentation and to relieve the deterioration degree of forest ecosystems. The location information of edge forest is strongly related to the edge effects. It is well known that total amount of a landscape edge plays a very important role in many ecological phenomena. In landscape ecological investigations, much of the presumed importance of spatial pattern is related to edge effects. The forest edge effect primarily results from the differences in wind and light intensity and quality reaching a forest patch that alter microclimate and disturbance rates. These changes, in combination with changes in seed dispersal and herbivores, can influence vegetation composition and structure.

Uncertainties

This research produced some valuable information on the forest fragmentation over the three major forested areas of China. However, it should be noticed that all analyses of forest fragmentation in the present study would be somewhat affected by the uncertainties in the original dataset. Because the classifications of TM imagery into land cover types are never completely accurate and the errors of aggregation conversion from 30 m to 250 m by implementing the majority filtering do exist. Specifically, the misclassifications in the original dataset affected the accuracy of forest area presented in this study, and the connectivity of forest patches closely associated with the measurements of all metrics described earlier. In other words, the presented results are slightly dependent upon the spatial resolution of land cover dataset used. In addition to above uncertainties, the fragmentation models used are also scale-dependent (Riitters et al. 2002), using another window size would produce another national map for forest fragmentation. However, the newly generated map does not alter the comparable relationship of fragmentation severity over the three forested areas, only modifying the percentages of six components of forest fragmentation in each of the forested areas (Fig. 2). If a finer land cover e.g., the original 30-m land cover for China, is available for forest fragmentation in the study, a new harassment may be appear due to the giant size of the data imposed calculation pressure upon the computer.

Conclusion

Land cover data derived from satellite remotely sensed imagery offers outstanding potential for analyzing and assessing forest fragmentation. This work successfully characterized the spatial patterns of forest fragmentation over the major forested areas of China by using the national land cover for 1995. The generated information provided valuable insights and implications as to the

fragmentation patterns. Southwest China had the highest severity of forest fragmentation resulted from the topographic segmentation and anthropogenic over-exploitation of forests, followed by the south region and northeast region. The generated national map depicting the forest fragmentation patterns was quite beneficial for various ecological applications, such as the planning and establishment of nature reserves, the conservation of biodiversity and genes etc. Also, the uncertainties presented in this study should be further investigated in the future.

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